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A review of ecosystems services trade-offs, synergies and scenarios modelling for policy development support

Uma revisão sobre serviços ecossistêmicos, trade-offs, sinergias e modelagem de cenários para apoio ao desenvolvimento de políticas

Priscila IKEMATSU[1,2*], José Alberto QUINTANILHA[1]

[1] Universidade de São Paulo (USP), São Paulo, SP, Brasil.

[2] Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT), São Paulo, SP, Brasil

[*] E-mail of contact: priscilai@ipt.br

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ABSTRACT: Information about the effect of land management on ecosystem services is essential to make balanced decisions, develop sustainable political strategies, and determine future scenarios. Previous methods and tools have been developed to analyze the effects of land use/land cover on ecosystem services. Nevertheless, being able to model the uncertainties, complexities, interconnections, and different interactions between multiple drivers of change in future scenario analysis are still a challenge in ecosystem service research. Modelling ecosystem service trade-offs and synergies and evaluating their use in scenario analysis are important issues that require more understanding. Therefore, this study explores the link and relationships among scenarios, models, and ecosystem services that support the decision-making processes. Based on electronic database publications, a conceptual framework illustrating the key components of this approach is presented. Further implications in terms of innovative tools that aim to identify pathways towards sustainable and balanced land use are also presented. It was concluded that spatial modelling of ecosystem services relationships associated with scenario building allows decision makers to better understand the complex interactions that occur in social-ecological systems. This approach brings important elements to set decisions, strategies, regulations, and policies for holistic land-use planning and management at different scales, notably in Brazil, a large and environmentally diversified country.

Keywords: ecosystem services modeling; land use management; future scenarios; decision making; environmental policy.

RESUMO: Informações sobre o efeito do manejo do uso da terra nos serviços ecossistêmicos são essenciais para tomar decisões equilibradas, desenvolver estratégias políticas sustentáveis e construir cenários futuros. Diversos métodos e ferramentas foram desenvolvidos para analisar os efeitos do uso/cobertura da terra nos serviços ecossistêmicos. No entanto, ser capaz de modelar incertezas, complexidades, interconexões e diferentes interações entre os vários vetores de mudança em análises de cenários futuros ainda é um desafio na pesquisa em serviços ecossistêmicos. Modelar trade-offs e sinergias entre esses serviços e avaliar o seu uso na análise de cenários são questões importantes que requerem mais entendimento. Portanto, este estudo explora o vínculo e as relações entre cenários, modelos e serviços ecossistêmicos como subsídio aos processos de tomada de decisão. Com base em publicações de bancos de dados eletrônicos, é apresentada uma estrutura conceitual que ilustra os principais componentes dessa abordagem. Outras implicações em termos de ferramentas inovadoras que visam identificar caminhos para um uso sustentável e equilibrado do solo também são apresentadas. Conclui-se que a modelagem espacial das relações de serviços ecossistêmicos associada à construção de cenários permite aos tomadores de decisão compreender melhor as complexas interações que ocorrem em sistemas socioecológicos. Esta abordagem traz elementos importantes para definir decisões, estratégias, regulamentos e políticas para o planejamento e gestão holística do uso da terra em diferentes escalas, notadamente no Brasil, um país grande e ambientalmente diversificado.

Palavras-chave: modelagem de serviços ecossistêmicos; gestão do uso da terra; cenários futuros; tomada de decisão; política ambiental.

1. Introduction

Ecosystem services (ES) are the goods/benefits that ecosystems provide to people (MEA, 2005) as well as their direct and indirect contributions to human well-being (Kosmus *et al.*, 2012). Human pressures on natural resources have resulted in many ES changes, affecting biodiversity, natural habitats, food production, quality and quantity of fresh water, distribution of species, air quality, and pollution levels thereby affecting human well-being (Carpenter *et al.*, 2005; MEA, 2005; Hernandez *et al.*, 2010; Grizzetti *et al.*, 2016).

After the Millennium Ecosystem Assessment (MEA, 2005), the importance of ES for human well-being was well established, which was reflected on the increasing number of scientific papers focusing on interrelations between nature and society through ES approaches (Barral & Oscar, 2012). Numerous possible applications exist including sustainable management of natural resources, land use optimization, environmental protection, nature conservation and restoration, landscape planning, nature-based solutions, climate protection, disaster risk reduction, and environmental education and research (Burkhard & Maes, 2017).

Assessing the mechanisms behind relationships between services (Bennett *et al.*, 2009), such as trade-offs and synergies, is a key challenge for decision makers (Lee & Lautenbach, 2016) because it provides information to identify pathways that minimize negative interactions and enhance positive ones.

Consequently, ES relationship analysis has become an important topic in ES research because they allow decision makers to predict ecosystem changes based on possible future land use scenarios and create a better understanding of the corresponding effects of different land management choices (Deng *et al.*, 2016).

Many studies have explored trade-offs and synergies among the four categories of ES (provisioning, regulating, cultural, and supporting services) recognized by MEA (MEA, 2005). Furthermore, various fields have been analyzed using the ES approach, such as agriculture, tourism, energy, and ecological restoration. These fields encompassed different geographical features worldwide, including urban context (Haase *et al.*, 2012; Lauf *et al.*, 2014), urban–rural complexes (Yang *et al.*, 2015; Moein *et al.*, 2018), watersheds (Tian *et al.*, 2016; Li & Wang, 2018; Li *et al.*, 2018), protected areas (Harmáčková & Vačkář, 2015; Kovács *et al.*, 2015), and natural places such as forests (Wang & Fu, 2013; Gonzalez-Redin *et al.*, 2016; Pang *et al.*, 2017; Sacchelli, 2018), mountains (Sherrouse *et al.*, 2017), plateaus (Feng *et al.*, 2017), and marine environments (James *et al.*, 2013).

Even though ES trade-off and synergy studies have the potential to become a major tool for policy development and decision-making on global, national, regional, and local scales (Burkhard & Maes, 2017), practical applications for real-world planning processes (Förster *et al.*, 2015; Bendor *et al.*, 2017; Cord *et al.*, 2017) and land management decisions (Rounsevell *et al.*, 2010; Geneletti, 2013; Deng *et al.*, 2016) using spatial integrated approaches (MEA, 2005; Nelson *et al.*, 2009; Turner *et al.*, 2016; Cord *et al.*, 2017) and scenario building (Deng *et al.*, 2016; Hu *et al.*, 2018) are among research gaps that need to be addressed.

Additionally, the gap between science and practice, or the application of scientific knowledge to face society's challenges (science-policy gaps), is another issue for effective decision-making, because it depends on how knowledge is produced and communicated/integrated. Different levels of policy formulation also influence the process - at the macro-level, the complexity can be greater and the ambiguity brought by science can further complicate the debate, while at the local level of frontline practice and management, there may be fewer factors to be addressed (Bertuol-Garcia *et al.*, 2018).

Another point of translating science into policy is scientific uncertainty. Whereas scientists are familiar with uncertainty and complexity, the public and policy makers often seek certainty and deterministic solutions (Bradshaw & Borchers, 2000). So fostering joint knowledge-production processes between scientists and decision-makers as well as interdisciplinary research across Ecology, Conservation and Political Science is needed (Bertuol-Garcia *et al.*, 2018).

Pires *et al.* (2018) mention that Brazil has an unique opportunity to develop research on their links with human well-being due to global relevance the country's stock of biodiversity and ES. Considering that biodiversity research on the links with ES and human well-being in Brazil is in its early phases, they have recommended the promotion of studies that explore multiple relationships between humans and nature.

This paper, therefore, was organized to review: 1) Ecosystem service relationships and scenario approach; and 2) methods to model ecosystem services relationships. Based on publications available on electronic databases, a comprehensive assessment of existing academic research was conducted to explore how the analysis of relationships between ES and spatial modeling improve scenario-building processes, helping to understand different land management effects on ecosystem and human well-being and to identify pathways towards sustainable and balanced land use.

2. Methods

A broad systematic literature review of peer-reviewed articles was conducted using the science direct and google scholar database to capture scientific papers and relevant reports, as those related to Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework (Díaz *et al.*, 2015). The search was restricted to the period between 2005 (year of publication of Millennium Ecosystem Assessment) and 2019. An initial screening of articles was done using the following keywords: ‘‘ecosystem service*’’ AND ((synerg*) OR (trade-off* OR trade off* OR tradeoff*)) AND “scenario*” in ‘Title, abstract or author-specified keywords’.

Then, the following selection criteria was applied to select the papers that were used in this review: (i) relevancy of abstracts and conclusions; (ii) articles that were not written in English were removed; (iii) the relationships identified between services (synergy, trade-off or no relationship) were the main topic; (iv) the method used to evaluate ES relationships was spatial analysis; (v) future scenarios were elaborated comparing the ES.

Accordingly, this paper was structured as follows. Section 3 presents a conceptual framework on the link among scenarios, models and ES relationships in policy and decision-making. Section 4 explores different models and tools for evaluating ES, their relationships, and their association with drivers of changes. Ultimately, at Section 5, we discuss some challenges and opportunities for decision-makers and planners to take appropriate land-management measures considering ES trade-offs and synergies and scenarios modelling.

3. Ecosystem service relationships and scenario approach

Scenarios are designed to explore a wide range of circumstances with varied aims, such as testing possible impacts, assisting policy-making and decision-making, promoting raising awareness and stakeholders’ engagement, developing innovative research, and understanding the changes in ecosystems and the services they provide (Peterson *et al.*, 2003; Carpenter *et al.*, 2005; Lambin & Geist, 2006; Hernandez *et al.*, 2010; Kepner *et al.*, 2012).

Scenario-building for ES analysis is an approach applied in the MEA (2005) to clarify key issues that might otherwise be missed or dismissed, as well as suggesting answers and guidance for action. The central idea behind scenario-building is to examine multiple plausible, possible, probable and/or preferable futures for one or more components of a system, based on a coherent and internally consistent set of assumptions about driving forces, uncertainties and unknowns, key relationships, and certain approaches or decisions (Peterson *et al.*, 2003; Carpenter *et al.*, 2005; Lambin & Geist, 2006; Hernandez *et al.*, 2010; Kepner *et al.*, 2012; IPBES, 2016; Kröger & Schäfer, 2016).

Scenario analysis in ecosystem assessments, policy support, and decision-making aims to visualize future impacts on ES and human well-being as a result of global, regional, and local changes such as land use, invasive alien species, over-exploitation, climate change, and pollution. This analysis approach provides support for decisions related to developing adaptive management strategies and exploring the implications of alternative social-ecological development pathways and policy options. At the same time, scenario analysis and scenario planning have been successfully applied in national, regional, and global assessments (Burkhard & Maes, 2017). There has been an increasing number of ES analyses that include demonstrating future changes using different scenarios/policies (Hasegawa *et al.*, 2018). In policy implementation, scenario and model approaches are often used to help identify which landscape activities will be allowed or encouraged in order to achieve landscape-level objectives for a range of criteria such as agricultural productivity, tourism service provision, and biodiversity conservation (IPBES, 2016).

Drivers are the foundation of scenarios because they shape the direction, magnitude, and rate of future landscape and seascape modifications (Mckenzie *et al.*, 2012). Direct/indirect drivers (MEA, 2005) are the factors, both natural and human-induced, which cause ecosystem change (Carpenter *et al.*, 2005; Nelson, 2005; Nelson *et al.*, 2009). Direct drivers (e.g., habitat change, nutrient enrichment, pollution of air, land, and water, overexploitation of terrestrial, marine, and freshwater resources, climate change, invasive alien species) have an explicit effect on ecosystem processes (Nelson, 2005), usually causing physical change that can be identified and monitored (Ash *et al.*, 2010). In contrast, indirect drivers (e.g., demographic changes, economic growth, shifts in socio-political and policy trends, cultural and behavioral changes, and advances in science and technology) operate more diffusely by altering the level or rate of change of one or more direct drivers (Nelson, 2005; Ash *et al.*, 2010). Both types of drivers often operate synergistically, and the combined impacts of various direct and indirect drivers have resulted in significant ES changes (Carpenter *et al.*, 2005).

The assessment of relationships among ES involves identifying what kind of associations occur in time and space as a result of different drivers of changes. When an overall ES relationship is altered, changes in one ES may modify the state of other ES. These changes can be unidirectional, bidirectional, or multidirectional; positive/synergistic, negative/conflicting, or null. Changes may be a result of shared drivers or ecological processes, or through true interactions among services (Bennett *et al.*, 2009; Mouchet *et al.*, 2014; Spake *et al.*, 2017).

The term trade-off has become very popular in ES literature, analyzing spatial and/or temporal co-occurrences of ES. This concept has predominantly been used to show opposing trends in ES associations and to identify a "win-lose" or "lose-win" situation that involves a decrease in the supply of certain types of ES, either directly or indirectly, because of an increased use of other types of ES (Rodríguez *et al.*, 2006; Bennett *et al.*, 2009; Haase et al,. 2012; Mouchet *et al.*, 2014; Kain *et al.*, 2016; Tomscha & Gergel, 2016; Cord *et al.*, 2017; Li *et al.*, 2018; Turkelboom *et al.*, 2018).

In turn, a "win-win" situation or positive interaction that involves a mutual improvement of two or more ES is typically called a synergy (Scholes *et al.*, 2010; Haase *et al.*, 2012; Howe *et al.*, 2014; Mouchet *et al.*, 2014; Kain *et al.*, 2016; Lee & Lautenbach, 2016; Tomscha & Gergel, 2016; Spake *et al.*, 2017; Li *et al.*, 2018). Some authors use synergies to describe changes made in the same direction, encompassing both win-win and lose-lose situations, situations in which both services either increase or decrease (Bennett *et al.*, 2009).

When two or more types of ES do not appear to increase or decrease, i.e., an improvement in one ES and no obvious changes in the other ('win-no change') or a decline in one ES and no obvious changes in the other (lose-no change) (Haase *et al.*, 2012), a 'no relationship/no-effect' relationship (Hamilton, 2008; Lee & Lautenbach, 2016; Li *et al.*, 2017; Li *et al.*, 2018), or co-existence (Kain *et al.*, 2016), occurs. Individual or bundles of ES can be an object of analysis.

Bundles have been used for investigating interactions among ES, positively or negatively associated, that repeatedly occur together in space or time, across a landscape, and are demanded by different groups of stakeholders (Raudsepp-Hearne *et al.*, 2010; Spake *et al.*, 2017). Wright *et al.* (2017), for instance, searching the literature to identify and classify formats used to present combinations of ES information for decision making, concluded that bundle maps and diagrammatic representations of bundles as the most likely to support decision--making-based on salience, credibility and legitimacy criteria.

Stakeholders and their differing values, interests, needs, power, and choices are key elements in ES relationship analyses, because they are the prime actors that ultimately cause ES trade-offs and find solutions to alleviate conflict situations. Social, economic, institutional, and ecological factors influence stakeholders' choices in local settings; however, location-based studies focusing on the local specificities of trade-off mechanisms involving local knowledge are limited. The unidirectional knowledge, or one-way flow of knowledge from science to practice, influence democratic decision-making processes and is one of the causes of science-policy gap, as stated by Bertuol-Garcia *et al.* (2018).

In the context of policy implementation and decision-making[1], the study of ES relationships can be translated to land-use or management choices that alter one (or more) ES at the expense of the delivery of another (Turkelboom *et al.*, 2018), revealing the effect of an implemented land-use policy (Hu *et al.*, 2018). Thus, this kind of analysis has the potential to provide information to decision makers for better management strategies and policies (Carden *et al.*, 2013), helping to explore optimal land use patterns that can improve ES (Feng *et al.*, 2017; Sun & Li, 2017). Consequently, ES analysis can help reduce stakeholder conflict, contributing to a more informed and transparent decision-making process (Carden *et al.*, 2013). An assessment based on ES trade-offs is a powerful tool that can be used to design spatial policies and evaluate the effect of land use strategies on the capacity of the landscape to provide goods and services (De Groot *et al.*, 2010). Allowing the integration of ecological-social data in planning (Bendor *et al.*, 2017) helps to prevent negative environmental costs of land use plans or policies (Barral & Oscar, 2012).

As ES is a global approach, another important aspect is related to differences between worldviews, cultures and languages in achieving fruitful engagement and dialogue in different contexts. The research developed by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), for example, stresses the importance of integrating a range of mixed worldviews and practices regarding multiple values of nature, as highlighted by Coscieme *et al.* (2020).

Choices or management decisions made between alternatives that cannot be achieved at the sa-

[1] We consider decision makers "those people who are aware of the importance of decision made by them or at least reflect on the way these decisions are made", as defined by Wierzbicki & Wessels. (2000, p. 29).

me time result in changes of the types, magnitudes, and interactions of ES (Cord *et al.*, 2017) and may or may not be reversible (Rodríguez *et al.*, 2006). Such changes may be the result of explicit choices that arise without premeditation or awareness and can take place in the same location or in different areas (e.g., impacts on water-related ES in a watershed) because changes occur spatially (across locations) and temporally (over time) (Rodríguez *et al.*, 2006; Coates *et al.*, 2013; Howe *et al.*, 2014).

Moein *et al.* (2018) developed a categorization scheme of competitive land-use, outlining the relative effects of a corresponding scenario on the loss of agricultural fields and fertile soils. That study demonstrates the potential that scenario-based urban growth allocation efforts have for evaluating the trade-offs between various policy options and the loss of agricultural productivity, which might help decision makers design urban landscapes with less competition from farmlands. Another study, conducted by Sun & Li (2017), assessed the spatiotemporal changes and elaborated on alternative scenarios exploring optimal land use strategies that can provide greater ES values and minimize the trade-offs among various ES, providing a reference for sustainable development in urbanized regions of China. Gonzalez-Redin *et al.* (2016) evaluated implications and trade-offs between forest production and conservation measures to preserve biodiversity in forested habitats; the spatial models produced provided different alternatives for suitable sites that can be used by policy makers to support conservation priorities while addressing management options.

A conceptual framework to illustrate key components of interactions among scenario-building, trade-off analysis, and ES modelling used in decision-making processes is shown in Figure 1. This framework emphasizes a modelling approach in scenario analysis to integrate feedbacks and trade-offs across temporal and spatial scales among dynamic societal economic and natural systems, helping to address particularly complex challenges and guide decision making (IPBES, 2016). We also indicate the importance of considering available data, decision makers' involvement, as well as the complexity of relationships between ES and their drivers. Conceptual frameworks help to organize various ways of thinking about the subject at hand and are useful as a model to guide the assessment process. Although it is not possible to capture the whole reality in conceptual framework, simplification can be a useful and indispensable tool for clarifying and focusing an assessment process (Tomich *et al.*, 2010).

Among the different methods that can be applied to ES relationship analyses under future scenarios, Figure 1 highlights the modelling approach. A model is a simplification of reality that represents qualitative or quantitative descriptions of key system components and relationships between two or more sets of factors (IPBES, 2016; Dunford *et al.*, 2017). When used in ES research, models are generally used to predict ES changes or underlying environmental aspects from which ESs are derived (Dunford *et al.*, 2017). In combination with scenario-building, modelling, and mapping, multiple ESs have been used to clarify the causes of ecosystem change as well as the relationships among ecosystem processes (trade-offs and synergies) to help decision makers make smart and sustainable decisions benefiting human well-being.

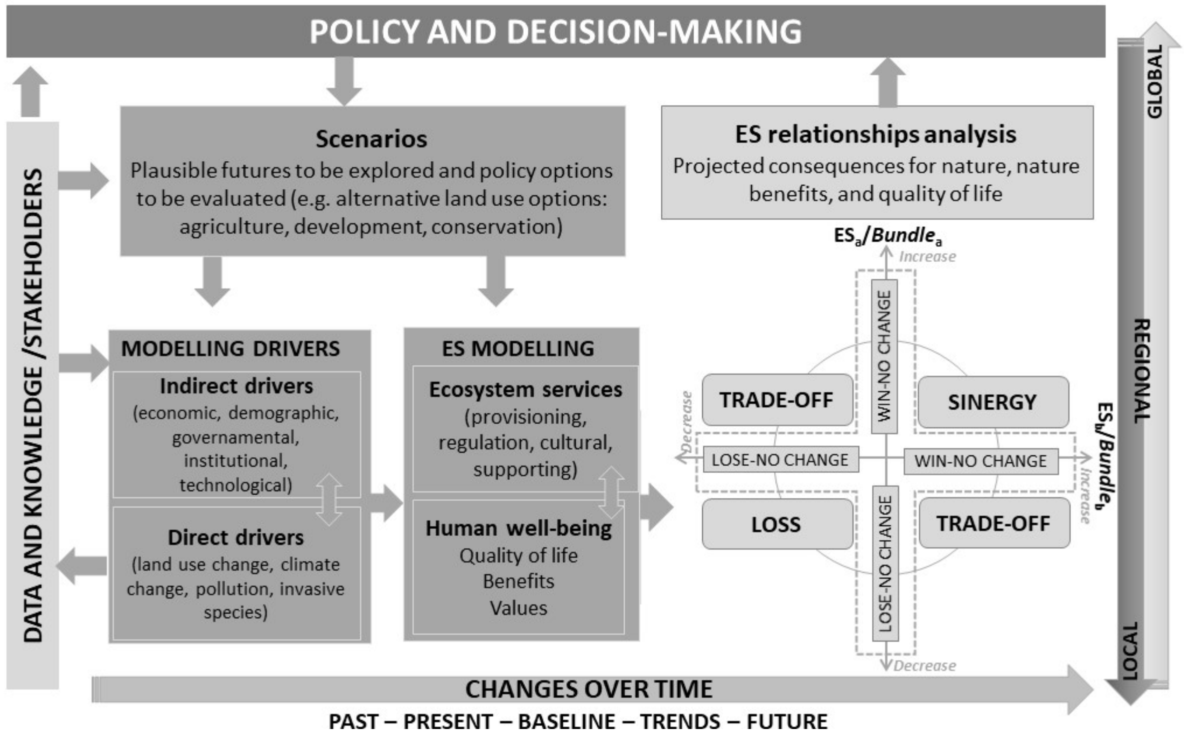

FIGURE 1 – Conceptual framework to illustrate the linkages between scenarios, models, and relationships among ES for informing policy and decision-making. The arrows represent the links between the elements of the framework.

SOURCE: Adapted from Haase *et al*. (2012); IPBES (2016) and Kain *et al*. (2016).

4. Modelling ecosystem services relationships

Models and scenarios that integrate trade-offs across temporal and spatial scales and among dynamic societal economic and natural systems can address particularly complex challenges and guide decision-making (IPBES, 2016). Moein *et al.* (2018), for example, studied the potential of scenario-based urban growth allocation efforts to evaluate the trade-offs among various policy options and assess the loss of agricultural productivity using a multi-criteria decision analysis and weighted linear combination map integration procedure. Mukul *et al.* (2017) conducted a study in Bangladesh identifying the crucial potential for ES framework on sustainable land-use planning and management in the Satchari National Park, concluding that ES assessment, maps, and scenarios were useful for selecting suitable management actions to achieve biodiversity conservation and protected area objectives in the country.

The use of different methods allows assessment of the current state of ESs (specific or bundle), their relationships, and the influence of drivers of change in scenario analysis. Burkhard *et al.* (2018); Dunford *et al.* (2018) and Harrison *et al.* (2018) mention the following group of methods according to the type of ES values they assessed: biophysical methods for mapping or modelling ecosystems; socio-cultural methods for understanding preferences or social values in ES (using multi-criteria analysis, ranking, and surveys); and monetary techniques for estimating economic values of services.

Based on literature review of peer-reviewed articles, a total of 33 tools that assess, quantify, model, value, and/or map ecosystem services was identified (Appendix 1[2]), as well as the main characteristic for their use for ES evaluation, including availability to the public (open source or private software), data needed, scale of application, skills required, the operational time necessary to run the model, ES modelled, datasets and examples of applications in research studies.

Integrated Valuation of Ecosystem Services and Trade-offs – InVEST, ARtificial Intelligence for Ecosystem Services – ARIES, Soil and water assessment tool – SWAT, Land Utilisation and Capability Indicator – LUCI and Resource Investment Optimization System model – RIOS are the most common tools supported by published peer-reviewed scientific studies.

Although the other tools presented in Appendix 1 have been recognized as specialized software for spatially modelling ES by different authors (Bagstad *et al.*, 2013; Turner *et al.*, 2016; Grêt-Regamey *et al.*, 2017; Ochoa & Urbina-Cardona, 2017; Shoyama *et al.*, 2017), they are only documented in technical project reports, websites and manuals, a situation consistent with the findings of Martínez-Harms & Balvanera (2012), Olosutean (2015) and Ochoa & Urbina-Cardona (2017). A better documentation of what is being mapped, how demand is quantified, and from what aim the maps are created are all essential to further operationalize ES assessments (Wolff *et al.*, 2015).

Some tools require affordable and tuition-training programs to ensure the correct use for spatially modelling ES; however, there are many user-friendly and open source modelling tools available as well. Various modelling frameworks and tools have undertaken innovative efforts in addressing the challenges mentioned, for example, combining quantitative indicator systems, spatially explicit mapping features, and qualitative stakeholder perception in a complementary way (Inostroza *et al.*, 2017).

Land use/land cover (LULC) data are key inputs for many ES assessments conducted using these methods. InVEST combines LULC data with supply and demand information for ES to provide a service output value in biophysical or economic terms (Sharps *et al.*, 2017). SWAT applies land use changes to model the effects on watershed yield, sediment, and agricultural pollutants in a river basin (Vigerstol & Aukema, 2011). The LULC change model outputs serve as inputs for ES models developed using the ARIES platform (Zank *et al.*, 2016). LULC models ES conditions and identifies locations where interventions or improvements might be delivered (Sharps *et al.*, 2017). Using widely available data on land use/management,

[2] Tools are organized from the most cited to the least cited in Appendix 1.

climate, soils, topography, and service demands, RIOS is able to provide both an investment portfolio as well as a set of land use scenarios that represent the portfolio implemented in the current landscape (Vogl *et al.*, 2017). In addition to the models for ES assessment, there are also specific models for LULC change such as Conversion Land Use and its Effects (CLUE); Land Transformation Model (Boumans *et al.*, 2015); Land Use Change Analysis System (Martinuzzi *et al.*, 2015); Slope, Land use, Exclusion, Urban extent, Transportation and Hill shade (SLEUTH), GEOMOD; UrbanSim; and Australian continental Land Use Trade-offs (LUTO) models, cited in Agarwal *et al.* (2002), Verburg *et al.* (2004), Lambin & Geist, (2006), Petz (2014) and Connor *et al.* (2015).

Scientific literature on modelling ES shows that models are used to add quantitative dimensions to scenarios, compare outcomes, evaluate the consistency of scenarios with known conditions and trends, and assess plausibility in relation to generally accepted mechanisms of ecosystem change (Carpenter *et al.*, 2005). Furthermore, because models can explore scenarios, trade-offs that result from different scenarios can subsequently be assessed. Grêt-Regamey *et al.*(2017) states that some ES modelling tools focus on scenarios, allowing for a better understanding of the impacts of different management practices on ES, such as the localization of ES provision hotspots, the analysis of synergies and trade-offs between ES, or the spatial comparison of supply and demand revealing areas under pressure.

Consistent reviews regarding analytical tools and approaches for quantifying ES synergies and trade-offs on the supply and demand side has recently been published (Howe *et al.*, 2014; Mouchet *et al.*, 2014; Deng *et al.*, 2016; Cord *et al.*, 2017; Spake *et al.*, 2017). These quantitative methods include GIS-based spatial statistical approaches without spatial analysis, integrated modelling framework, and approaches based on the multi-criteria analysis. Assessments that use GIS-based spatial mapping through correlation analysis (for interactions between pairs of ES) or cluster analysis (for ES bundles that are associated in space by delineating spatial units) provide detailed information on ES indicators and assist in understanding and visualizing potential trade-offs via maps and diagrams (Raudsepp-Hearne *et al.*, 2010; Mouchet *et al.*, 2014; Deng *et al.*, 2016; Cord *et al.*, 2017; Spake *et al.*, 2017).

Statistical approaches without the use of spatial analysis (e.g., correlation analysis, regression analysis, cluster analysis, and redundancy analysis) can be used to identify the general direction and strength of trade-offs and synergies (Mouchet *et al.*, 2014; Cord *et al.*, 2017; Li *et al.*, 2018). In integrated modelling framework for systemic assessments, the outputs of one model may be used to provide inputs for another model, creating modelling chains such as InVEST, ARIES, SWAT, LUCI, and RIOS. Multi-criteria analyses are approaches that deal with the implicit trade-offs introducing weights given by both individual decision makers and groups of stakeholders to analyze preferences for different decisional outcomes (Deng *et al.*, 2016; Dunford *et al.*, 2017).

In addition to quantitative methods, qualitative techniques and participatory models may be useful for studying drivers of ES trade-offs, synergies, and bundles. These approaches could include interviews and focus group discussions (Cord *et al.*, 2017). The involvement of scientists, local experts and stakeholders in this process enhances the credibility, salience, and legitimacy of ES relationship information, provides inputs for assessment tools, supports interpreting early results, creates a mutual understanding of the problem, and educates how to use outputs to inform decisions (Ruckelshaus *et al.*, 2015). Daw *et al.* (2015), for example, identified ES trade-offs and their drivers, and evaluated resulting stakeholder perception. Kovács *et al.* (2013) assessed local stakeholder perception of trade-offs between ESs at three protected sites in the Great Hungarian Plain using qualitative methods. Adams *et al.* (2016) analyzed land-use scenarios using expected stakeholder satisfaction with changes in the catchment to explore how these scenarios performed against social preferences. Darvill & Lindo (2016) quantified different use for 15 cultural and provisional ecosystem service indicators across seven stakeholder groups in a watershed environment.

Once ESs have been quantified, spatial and temporal trends in the distribution of two or more ES values can be compared to find significant associations or interactions among them. Assessing current ES relationships provides a baseline for comparing alternative future scenarios and insights into potential outcomes of policy and management decisions (Mouchet *et al.*, 2014).

5. Challenges and opportunities for ecosystem services in policy development support

Modelling ecosystem services and its trade-offs and synergies can be useful for predicting changes and effects of land management choices on its fragile ecosystems.

Nevertheless, relations among ES are not stationary in space and time, which makes the complex temporal and spatial ecological dynamics difficult to model. The non-linear dynamics among ES in different trajectories that social-ecological systems can undergo, driven by both biophysical drivers and management decisions, imply that the analyses have to deal with multiple dimensions, interactions, variations, and uncertainties with different physical units across time and space (Cavender-Bares *et al.*, 2015; Deng *et al.*, 2016). Moreover, ES relationships often have ramifications far beyond the decision that has led to the trade-off itself and may affect nearby services, faraway services, future services, or secondary services, and might have serious implications for making trade-off decisions (Rodríguez *et al.*, 2006).

The importance of including society and multiple stakeholders in future scenario analyses to accurately assess ES relationships for policy and decision-making is notable. A more participative approach to define when and what kind of ES relationships information is needed ("value for whom?" and "value as of when?") is critical to inform decision-making, policies, and implementation (Ruckelshaus *et al.*, 2015; Dunford *et al.*, 2017).

Despite this relevance, it is difficult to consider different values in different social contexts in response to changing environmental, socio-economic, or political factors, such as a changing climate, political tensions, trade bans or new supply opportunities given that values are not static and vary depending on which groups place a value on ESs (Dunford *et al.*, 2017).

In this sense, it is pressing to advance in the knowledge and innovation associated to the adoption of flexible measures of adaptive management and the implementation of practices of socio-environmental governance in an integrated and interdependent perspective based on ES approach.

Spatial modelling of ESs is an emergent research field (Ochoa & Urbina-Cardona, 2017) and innovative methods for scenario building, ES analysis, and land management practices have great potential to create customized solutions that address practical user needs and to support full integration of the ES framework into land-use planning and policy-making.

Scenario-building and ES relationship analysis can provide a useful way to evaluate the complex interactions within and between natural and human systems, and to predict the effects of ES management or policy actions. The use of modelling approaches to predict ES changes based on possible future land use scenarios allows decision makers to better understand the corresponding consequences of different choices and achieve a solution for the long-term sustainable development of socio-ecological systems (Deng *et al.*, 2016). Additionally, modelling the current state of ecosystems, their drivers of change, and effects on their function over time can inform decisions, strategies, regulations, and policies at different scales which will shape future management in different scenarios (Atkins *et al.*, 2011; Bastian *et al.*, 2012; Bastian *et al.*, 2013).

Some examples of this approach for the decision-making process have recently been developed. Gong *et al.* (2019), for instance, conducted a study in a mountain-basin area in western China. They analyzed different tradeoffs/synergies relationships illustrated for different land use scenarios. The win-win scenario was used for guiding strategies for sustainable land use and ecosystem management in this area. Hu *et al.* (2018) put forward four feasible future land-use scenarios (convert paddy land to dry land) and selected an optimal one based on trade-offs among ecosystem services. The study demonstrated the utility of scenario analysis in providing a scientific basis for land-use decisions that integrated social, cultural and physical concerns.

Brazil is a large and environmentally diversified country, but despite these characteristics, there are still several environmental problems that threat the biodiversity and natural resources in this area. Parron *et al.* (2019) have summarized current knowledge regarding ES in Brazil in order to provide a basis for future research in the country. They concluded that this topic is in full debate by the scientific community, probably because it is recent, and therefore reviews and analyses of work in this area must be consolidated so that consensus may be reached.

Thus, we recommend future work that should address ES interactions and ES bundle dynamics ranging from pristine to highly modified landscapes in time and space. The integration of spatial ES assessment data into planning and decision-making through innovative methods appear to be an important approach for holistic land-use planning and management in the country.

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